NATURAL PROCESSES INVOLVED IN THE FORMATION OF PLEISTOCENE BONE ASSEMBLAGES IN CONTINENTAL SOUTH-EAST ASIAN CAVES: THE CASE OF THE CAVE OF THE MONK (CHIANG DAO WILDLIFE SANCTUARY, THAILAND).

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Abstract: A large paleontological assemblage typical of *Ailuropoda-Stegodon* fauna was discovered in the Cave of the Monk, in northern Thailand. Geological and taphonomic approaches were conducted in order to determine site formation processes. A sedimentological study indicated that the fossiliferous layer resulted from medium-size burrowing animals occupying the cave. Bone surface analysis confirmed that Porcupine was the main, if not exclusive, bone accumulator. A bone accumulation rate was calculated. The assemblage appears to have formed over an average period of one to several tens of thousand of years. This time frame means that the assemblage can not be considered as a homogeneous reference for palaeoenvironmental reconstruction as may have been assumed without the present analysis.

Keywords: Thailand, cave, geology, taphonomy, porcupine.

Introduction

To date, there is no general study describing the formation of faunistic sites in a karstic context in Southeast Asia. As a consequence, any bias in mechanisms which led to the accumulation of bone remains or limitations in the use of the collected series for documenting the biostratigraphy or reconstructing the paleoenvironment are not known.

This present study aims to fill in these gaps in knowledge. We conducted a pluridisciplinary study at the site in the Cave of the Monk in Thailand. Geological and taphonomic approaches were combined in order to determine site formation processes. We discuss the implications of the

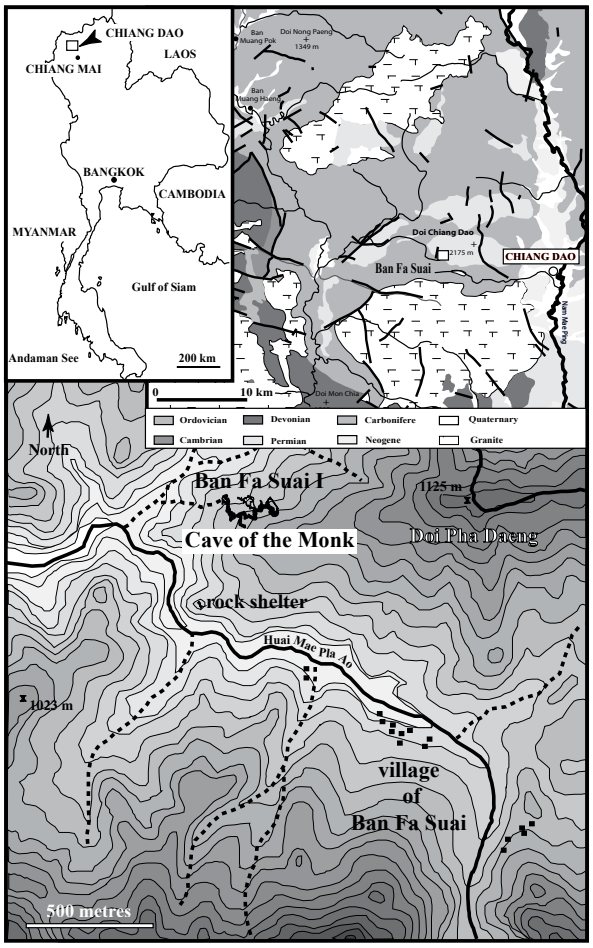

Figure 1: Site location.

formation processes in regard to the paleoenvironmental and biostratigraphic significance of the assemblage.

Study site

The Cave of the Monk (N19° 24,603' ; E98° 48,985') is close to Ban Fa Sui, 80 km north of Chiang Mai (Zeitoun *et al.* 2005) (Fig. 1). The cave opening is at an altitude of 900 m in a dry tropical forest. The surrounding countryside is characterised by average sized mountains, dominated by Doi Chiang Dao which at 2716 m is a major peak on the regional horizon. This limestone block is highly karstic (Delange 1997), as are the surrounding limestone outcrops. The site was found within one of these karstic outcrops. The cave is in the highest section of three levels of galleries connected by separate narrow shafts. The lower section of the network is active and a tributary of the Huai Mae Pla Ao river flows through it.

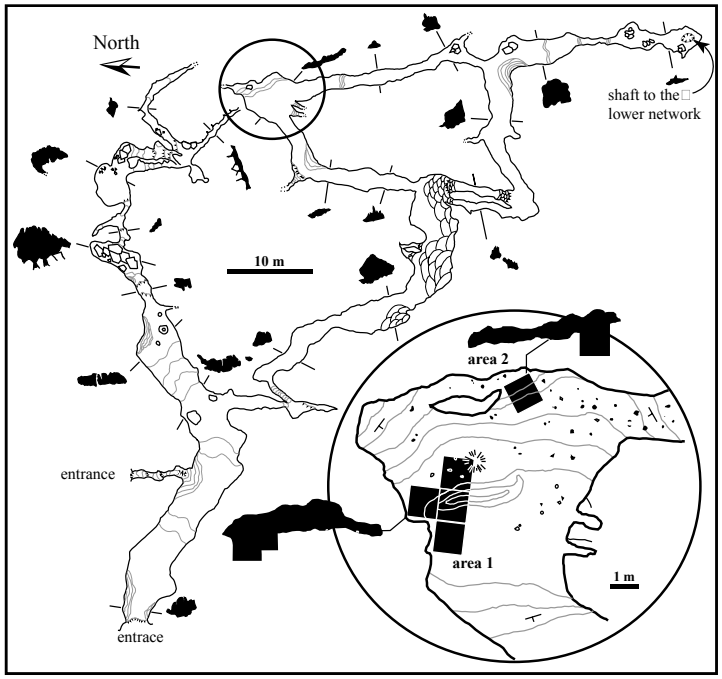

Figure 2: Map of the Cave of the Monk with a detailed map of the lower chamber and survey locations.

The Cave of the Monk is named after its entrance which is used as a meditation room. A corridor leads from this first chamber for approximately 30 meters (Fig. 2). After that the gallery divides into northern and southern branches. Several meters after the corridor, the south banch of the cave can be accessed from below through a narrow passageway. This branch is accessible for approximately 40 metres. It is then necessary to crawl through a squeeze before to reach a lower chamber. It was in this chamber, which is approximately 100 metres from the entrance, that excavation led to the discovery of most of the fossils.

The excavation consisted of two test-pits (Fig. 2). The first was near the entrance to the room (test 1) and the second deep within the chamber (test 2). The total surface covered was 5 m^2. The paleontological remains were found within the first 50 cm of sediment. To ensure that the recovery of material was complete all of the articles found during the dig were labelled and their exact position noted. Then, each layer of removed sediment was sieved with water and a 1.3 mm sieve and once dry all remains larger than this were kept.

A large number of species and genera were identified within the assemblage (*cf.* Zeitoun *et al.,* this volume: 52). The level of identification at the genus level was significantly high: 31.6 %, but it was low at the species level: 9.1 %. The assemblage includes remains of Stegodon, Panda and Pongo, that is one fossil species and two species now extinct in this region. On this basis the assemblage can be classed as type *Ailuropoda-Stegodon*. The absence of archaic species suggests that this assemblage is characteristic of the faunistic group known as Yenchingkou II which, according to Han et Xu (1985) was present in the late Pleistocene in southern China. Nevertheless, we can not be overly confident with this assessment because modern Hyena, *Crocuta crocuta ultima,* which replaced *Hyena sinensis* (Kurten 1956 ; Ginsburg *et al.* 1982), is the characteristic species of this biozone and we did not identify this taxon in the assemblage.

Materials and methods

Geological study

The site context was described by examining the organisation of the karstic network, the morphology of the cave and its infilling. A cave temperature profile was also established by measuring the minimum and maximum daily temperatures at different places within the cave.

The stratigraphy of the site is based on the test pit sections. The deposits were described directly on site by noting their general organization, the texture of sediment and the clast morphology, the characteristics of the stratification and the occurrence of sedimentary features as grain size sorting or grading. Sediment colour was determined by reference to the Munsell colour code (Munsell 1954). The macroscopic description was completed with several laboratory analyses: particle size distribution of the deposit matrix (i.e. the sediments less than 2 mm) was determined by mechanical sieving and laser diffractometre analysis for the finest fraction (<50 μm), X-ray diffraction was used to identify mineral species, and thin sections, prepared from undisturbed blocks of sediment impregnated with polyester resin, were observed with a petrographic microscope.

The genesis of the so characterized deposits has been interpreted by comparison with actual analogues.

Taphonomic study

Artefacts found on the surface in the north branch of the cave will not be taken into consideration in this study. The studied series (3,709 remains) was collected from the surface in the entrance to the chamber and during the excavation.

Each paleontological remain was examined by eye and if necessary with a magnifying glass. For each bone or tooth we noted: the state of fragmentation, the colour and the surface state. For this last parameter we were looking for any man-made alterations (*e.g.* Traces of fire/combustion, cutmarks, percussion marks), biological alterations (digested or regurgitated bones, gnawing, edge damages, punctures) and alterations caused by corrosion (polish, smoothing, patina). Finally the dimensions of each remain were measured with a caliper.

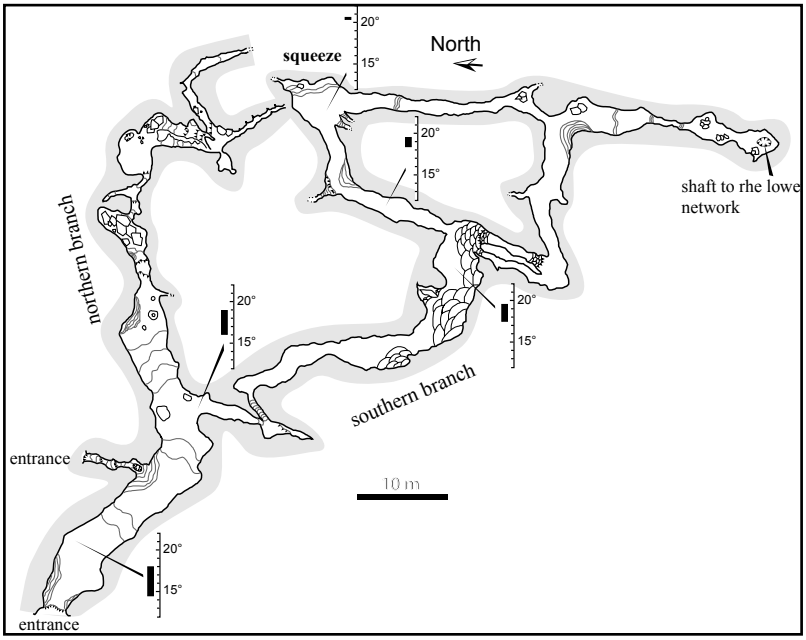

Figure 3: Daily temperature fluctuations (° C) measured at different places in the cave.

Results

Geological study

The Cave of the Monk and notably the south branch is a natural gallery with a relatively constant diameter. Large speleothems and gours occur frequently. The lower chamber, however, is uncemented. There, the soil surface is clayey and consists of juxtaposed shallow basins (10-20 cm), less than one-meter large and bordered by flattened ring of compacted sediment. During the first exploration of the cave, one of these troughs was surrounded by porcupine quills (Fig. 2).

At several places in the cave, evidence of old infilling preserved against the walls and generally cemented by secondary calcite can be observed. These outliers consist of bedded sands and pebbles indicating an ancient alluvial stage. In the shaft above the narrow opening to the south branch, this conglomerate is overlain with fine sand and silt finely laminated.

The cave appears to have had a complex sedimentary history with at least 4 phases:

1. An ancient alluvial period during which an underground stream deposited a bed of sand and pebbles,
2. Sedimentation due to flooding of the cave network, perhaps in relation to a subsequent event where the water level sunk back into the massif, during which suspended material was deposited,
3. period of sediment remobilization, probably by draining in lower karstic levels,
4. A period of karstic fossilisation during which the speleothems formed.

The temperature measurements made in the area around the entrance during january, in the cold dry season,

Ech	Unit	commentary	Mineral
04.1a	rock	altered cortex	Hydroxylapatite (+++) cristallised
04.1b			Hydroxylapatite (++) well cris tallised Dittmarite (+) ?
04.1c			Hydroxylapatite (+++) very well cistallised Quartz (-) Smectites (-)
04.2	II	Indurations (10YR 6/8)	Quartz (++) Hydroxylapatite (+)
04.3			Quartz (++) Hydroxylapatite (-) Montgomeryite (-) Tarakanite (--)
04.4		brown deposit (10YR 6/6)	Quartz (+++) Hydroxylapatite (-) Muscovite (-)
04.5		yellow deposit (10YR 7/2)	Quartz (++) Hydroxylapatite (-) Leucophosphite (-) Muscovite 2M (--)
04.6		altered cortex of stone	Hydroxylapatite (++) well cristallised Quartz (-) Smectite (--)

Table 1: Minerals identified by X-ray diffraction. Phosphated minerals are indicated in bold. +++ : very common ; ++ : common ; + : slightly common ; - : rare ; -- : traces.

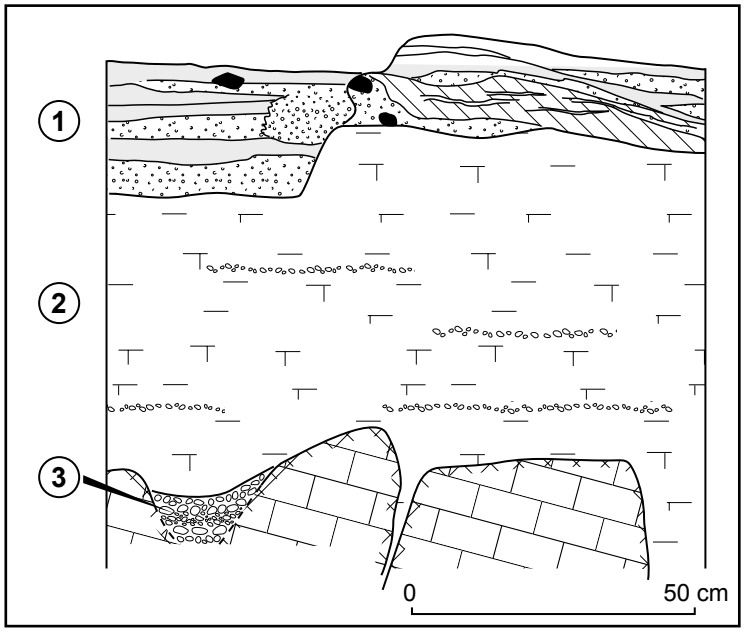

Figure 4: Stratigraphy of the deposits in the lower chamber of the Cave of the Monk observed on the east section of the first test pit. The numbers indicate stratigraphic units. *cf.* next figure for drawings legend.

showed a daily cycle with variations between 14 and 18° C (Fig. 3). The minimum temperatures were recorded at the beginning of the morning and the maximum temperature at the end of the afternoon, showing that the cave reaches a rapid equilibrium with the outside temperatures, which were identical. Air currents generated by these temperature fluxes run through most of the network. In the southern corridor these currents loose intensity after a division in two passages. They are no longer noticeable in the second half of the north branch.

The temperature of the deep karst, regardless of seasonal fluctuations, is 20.5° C. This value was determined by measuring the temperature of the stream water at its resurgence. This same temperature was also measured in the lower chamber, where no daily fluctuations were measured. We conclude that this location in the karstic network is not affected by air currents and that its thermic cycle is the same as the deep karst, with a constant year round temperature.

The infilling of the fossiliferous room has been described on the section of the first test pit. The bedrock was reached at a depth of 0.8 to 1 m. Its surface is irregular and presents a block crust made up of a centimetre thick alteration rim with alternating compact white and powdery black laminae. The mineralogical determinations indicated that it is mostly composed of phosphates (tabl.1).

The infilling consists of 3 stratified units (Fig. 4).

1.The third unit is only found in the hollows in the rocky substratum. The unit is 20 cm thick. It consists of horizontally bedded lenses of well-sorted calcareous granules and pebbles sorted by lenses with horizontal bedding and filled with a clayey red brown sand. The structure and composition of this deposit are the same as those of the breccia conglomerate observed against the walls of the cave.

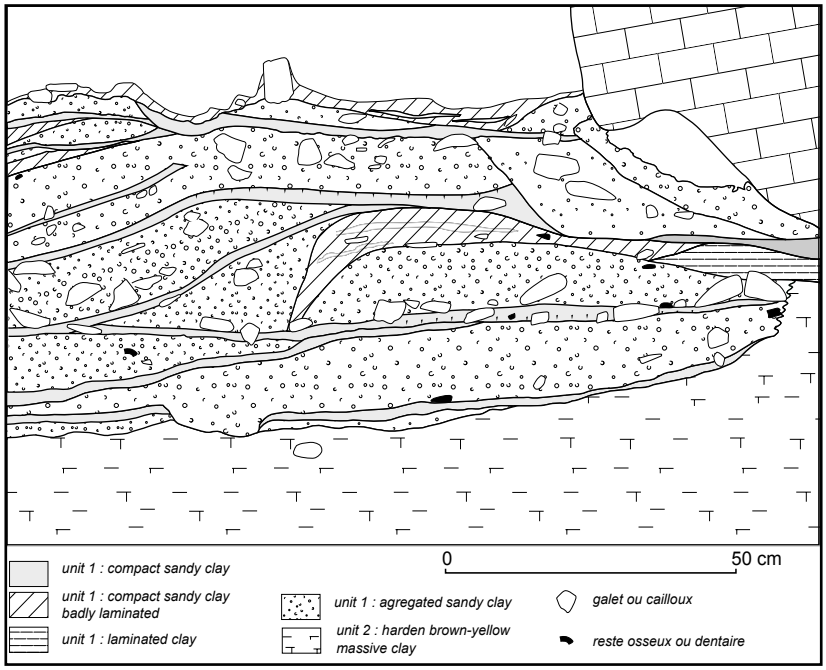

Figure 5: Detailed structure of stratified unit 1 observed at survey area 2.

2.The second unit overlays the first deposit as well as the highest parts of the bedrock. The sediment is a yellow-brown to yellow (10 YR 6/8) clayey sand which is more or less hardened. X-ray diffraction determined that the major minerals are phosphates (tabl. 1) which, in thin sections, look either like beige to yellow isotropic mass impregnating the deposit, or like a fibrous isopac coatings of hydroxylapatite. Subhorizontal layers of sediment which is aggregated or rich in granules were also observed in some spots. Under the microscope, the lithology of the granules is variable: pelite, sandstone and quartzite. Several pieces of granules are scattered in the deposit and have a very well developed phosphate-rich alteration rim (tabl. 1).

3.The first unit contains the paleontological remains.

It is 0.2 to 0.5 m thick. The irregular and sharp lower limit indicates an erosional contact. The deposit is a yellow-brown (75 YR 4/6) to red brown (7,5 YR 5/6) and, sometimes, grey brown sandy clay with few pebbles. The general facies is a stratified lenticular deposit. The lenses are no more than 10 cm thick. They are arranged in series of horizontal or slightly inclined conformably overlying lenses. The sets of lenses extend for more than one metre and their thickness reaches approximately 20 to 30 cm. Each set is separated by sharp or erosional surface (Fig 4 and 5).

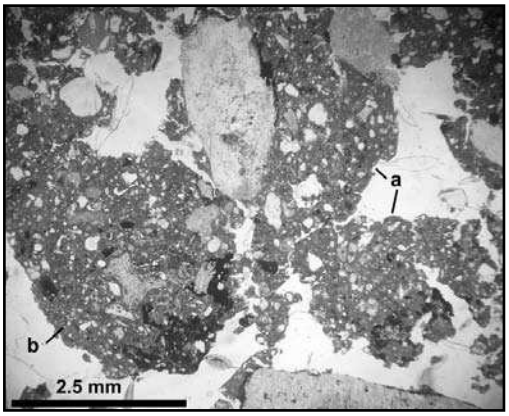

Figure 6: Microfacies of the fossiliferous unit (unit 1). Aggregated clay facies: note the smoothed surface of the aggregates (a) and the orientation of the clayey matrix at the periphery of the aggregates (b).

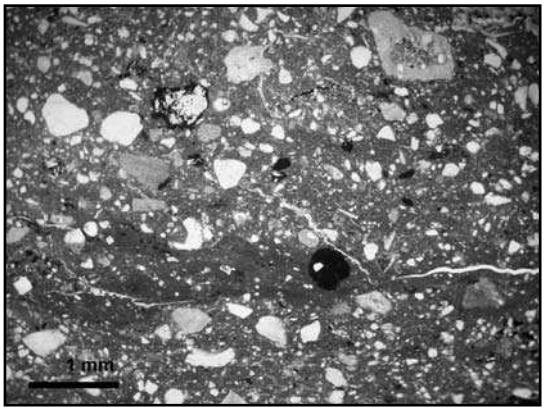

Figure 7: Microfacies of the fossiliferous unit (unit 1). Solid clay facies: note the irregular lamination with variations in the colour of the fine fraction and in the quantity of sand, and the sediment compactness which is associated with a fissural porosity parallel to the bedding plane.

In detail, each lens is formed by the superposition of two facies:

The base and the body of the lenses consist of millimetre to centimetre thick clayey aggregates. These aggregates are sorted and a single grading, most often normal, occurs frequently. Example of recurrent grading has been observed in some lenses. Aggregation is clear at the coarse-grained basal part of the lenses and lessens progressively towards the top. Associated to the coarser aggregates are small limestone pebbles which are smooth and sometimes completely weathered. The clast morphology, small triangular or square plates, indicates that these stones are derived of the surrounding rock that is fractured by a joint pattern. Dental remains were preferentially associated with the coarse-grained parts of lenses. In thin sections, aggregates are heterogeneous, due to variations in texture and colour. Also of note is the clay orientation observed art the periphery of the aggregates (Fig. 6).

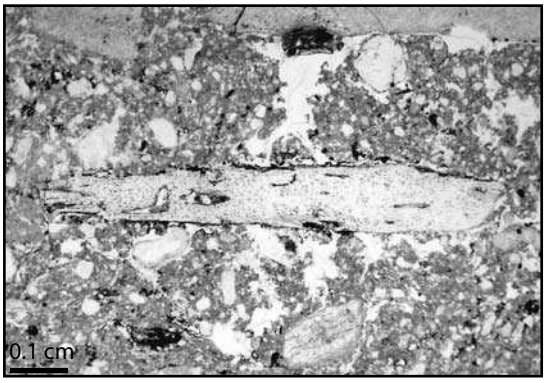

Figure 8: Details of a boney remain found in unit 1. Alteration is characterised by fine cracking at the bone periphery (detachment of thin slices) and the development of brown areas.

The upper part of lenses is composed of compact and massive clay (Fig. 7). This bed varies in thickness from 2 to 5 cm. It is especially pronounced when it forms the upper surface of a set of lenses. The lower boundaries of these beds are progressive where as the upper limit is sharp and sometimes highlighted by a pattern of desiccation cracks. Locally, intercalated laminae some centimetres thick can be distinguished. These have wavy borders and stand out due to variations in colour and texture. A clay orientation is also observed under the microscope; clays are orientated on the periphery of grains (sand or bone) or according to the bedding plane and, in the case of intercalated laminae, following the undulations of the sediment. In this massive sediment, porosity is weak, and consists of cracks parallel to the bedding plane.

The microscopic examination of the slides has shown an alteration of the paleontological material. This degradation was more or less pronounced but affected both bone and dental remains (Fig. 8). It is characterised by 1) cracking, 2) digestion holes along the walls, 3) the development of brown spots in a dentritic network and 4) the appearance of darkening zones with a loss of birefringence.

Our interpretation of the deposition mechanisms is the following:

At the bottom of the sequence (unit 3), sands and pebbles are evidences, preserved in the bedrock depressions, of an ancient alluvial period, which is also represented by the cemented conglomerate observed intermittently along the walls of the cave.

The second unit was originally a deposit of fine material transported by flow, as shown by several intercalate beds of granules. As is the case of the silt overlaying the alluvial deposits in the shaft, this is evidence of deposition related to cave flooding at a time where the river flowed in a lower karstic level. These sediments have undergone significant diagenesis. This is shown by the phosphate formation (mostly hydroxylapatite, *cf.* tabl. 1). These phosphates are derived from animal guano, very likely bat, because of the occurrence of Dittmarite in the mineralogical array which is an ammoniated phosphate of animal origin (Hill, Forti 1997). The diagenesis is pronounced. Among the phosphates identified are several mineralogical species that imply a complete decarbonatation of the sediment (tarakanite, leucophosphite and montgomeryite, *cf.* Karkanas *et al.* 2000). This type of transformation indicates that a hiatus took place between the edification of this unit and the overlying unit 1.

The unit 1 deposit is attributable to an accumulation of dug sediment by burrowing animals. Indeed, the round millimetric to centimetric aggregates facies observed, and which are commonly found in karstic context (Goldberg 2001), are associated with burrow infilling (Karkanas 2001). This interpretation is also

supported by the grain size sorting of the aggregates. The strips of digging debris which accumulate when a burrowing animal digs show a longitudinal sorting where the coarsest material ends up on the edge of the rejected layer. The accretion of this debris then leads to the superposition of material in progressively decreasing size (Lenoble 2001).

The progressive nature between the clay aggregates and the solid clay facies underneath it indicates that the solid clay layer was produced by the compaction of the aggregated sediment. The orientation of clay minerals observed under the microscope suggests that the deformed sediment is in a plastic state. The ill-defined bedding and the flattening observed (indicated by the wavy edges of the intercalated fine layers) are also evidence of this deformation. The compaction and the fissural porosity in accordance with the bedding plane suggest that it is a trampled horizon (Goldberg, Whitbread 1991). So we deduce that these compact beds are formed by an originally aggregated material.

The association between lenses of aggregates and beds of clay thus represent an episode of burrowing (production of aggregates) followed by a period of occupation of a burrow (formation of a trampled horizon). The succession of many lenses means that there were many burrowing events. The size and morphology of the digging can be determined from the geometry of the erosive contact between each set of lenses. These are suggestive of shallow depressions extending for about one metre. This morphology is identical to the troughs which presently structure the ground of the lower chamber. The sediment rings which delimit the troughs on the soil surface represent the strips of accumulated debris which have secondary been compacted by trampling. The stacking of a series of lenses indicated multiples phases of digging where the debris filled in the existing topography.

These beds are significantly smaller than those described for brown bears (Fosse *et al.* 2001). They were thus made by a medium sized animal. The porcupine quills surrounding on of these beds when the room was discovered suggests the digging was done by this rodent. This interpretation is supported by the present-day descriptions of the *Hystricidae* lair. Hughes reported a similar organisation of burrows and a central area flattened by trampling and used for sleeping: *« Inside the lair was a circular raised pieces of clean ground well consolidated by the porcupines that had lain there sleeping »* (Hugues in Brain 1981: 112).

Bone	**Teeth**		
	complete	**fragments**	
		enamel	**enamel & dentine**
		769	1,958
	297	2,727	
472	3,024		
total 3,496			

Table 2 : The kind of remains found.

Two other arguments also support this interpretation. First of all this area of the cave is exceptional in that the temperature does not vary, making it attractive for occupation by an animal. Secondly, unlike other galleries where puddles of water are present at some times during the year, the absence of concretions, on the ceiling or floor, is evidence that dripping is rare in this chamber which would also make it a more favourable place for a lair.

The sedimentological study indicated that the fossil deposit (unit 1) is associated with the use of the lower chamber as a lair. The formation of this deposit was late in the history of the karst. Indeed it was at the moment that the network became fossilised, meaning that there was no longer any alluvial deposition taking place. The cave has probably been frequented for a long time judging by the large number of beds which have remodelled the upper part of the room infilling and which reach a thickness of half a metre. This use of the cave appears to have continued to the present day since we found porcupine quills on the floor during our first exploration of the cave.

	petrosal	**phalanx**	**metapode**	**calcaneus**	**indet. fragment >3 cm**	**indet fragment <3 cm**	
N	71	9	5	5	18	354	462
%	15.4	1.9	1.1	1.1	39	76.6	100

Table 3 : The kind and number of average and large sized mammal bones (rodents are not included).

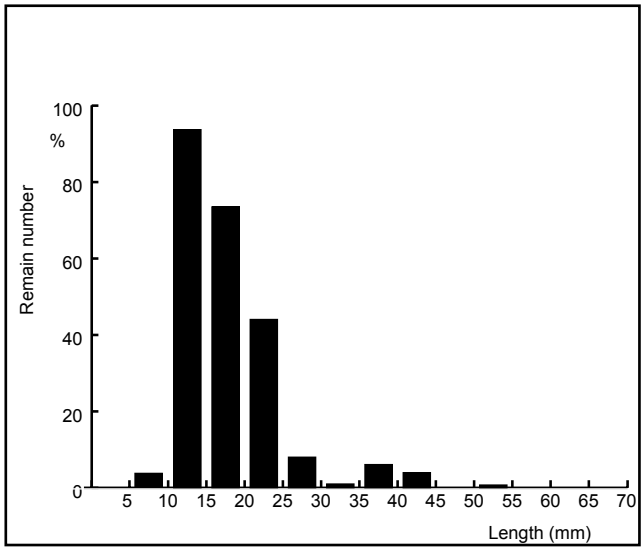

Figure 9: Distribution of bone fragment length.

Taphonomic study

The series of remains is mostly teeth (82.7%). A large majority is dental fragments made of enamel and dentine, but sometimes only enamel (Tabl. 2). The size of these fragments obviously varies greatly depending on the taxonomical origin of the remains. Nevertheless these are rarely larger than 3 cm.

	NR	NRr	Rr
fragmentary bones	472	368	78.0 %
teeth	3,024	562	18.6 %
complete tooth	297	149	50.2 %
enamel	769	0	0
enamel & dentine	1,958	413	21.1 %

Table 4 : Gnawing tracks NR is the number of remains ; NRr is the number of remains showing traces of gnawing; Rr is the rate of gnawing, in percentage. It represents the ratio of NRr/Nr.

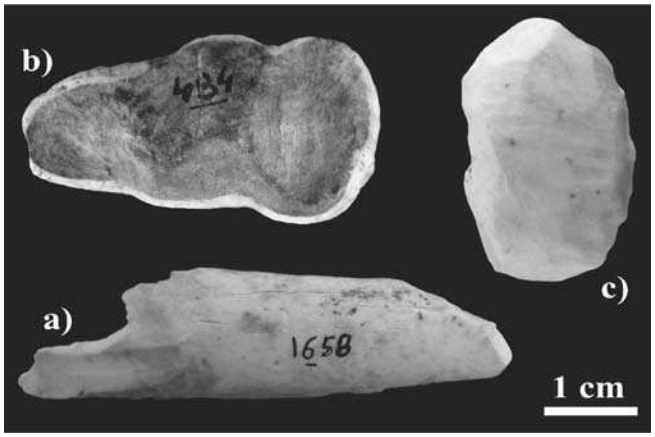

Figure 10: Example of gnawed bones. (a) fragment of long bone diaphysis gnawed at its ends. (b) a gnawed tooth root. (c) a bone showing multiple gnawed facets.

The majority of bone remains are small splinters for which identification is difficult. As for the teeth, their size is often less than 3 cm (Fig. 9). The largest bone artefact found, a fragment of large mammal long bone diaphysis, is not longer than 5.5 cm. Most of the identified bones are complete or almost complete and are not very diverse. For the most part, these are (tabl. 3): petrosal, phalanx, metapode and calcaneus.

We did not identify any traces of man-made alterations of bone, whether it be burn, cutting or percussion marks. Similarly, no modifications due to the action of carnivores: teeth marks, perforations, grooves, crenelated edges, traces of digestion, were observed. Alterations of biological nature were found in abundance, however, and are due to gnawing (Tabl. 4). Typically, this gnawing is seen as flat to concave plurimillimetric to centimetric facets, bearing groups of striations (Fig. 10a). Small numbers of these striations are grouped within shallow grooves, which are parallel to each other and sometimes slightly curved. Grooves are several millimetres wide and their bottom is slightly concave in a transverse plane.

From the size and morphology of these grooves these could be identified as gnawing marks made by a porcupine (Brain 1981; Pei 1938). The list of fauna from the site includes two taxa which could be the culprits of this gnawing: *Hystrix brachyura* and *Atherurus macrorus* (*cf.* Zeitoun *et al.*, this volume: 52).

Almost all of the bone fossils (78%) have traces of gnawing. When exhaustive, these gnawing cause the modification of the bone shape. Two noteworthy morphologies are produced by exhaustive gnawing:

- small compact prisms of bone the outside of which is formed exclusively of subvertical facets. These are 1 to 2 cm thick and approximately the same width with a length shorter than 3 cm. These pieces can have been completely shaped by gnawing (Fig. 10b), but sometimes the non-altered bone in which the plyedres was sculpted can be seen at the bottom or at the top surface. The ridges are arranged in a radial pattern. Some facets no more than a few millimetres wide show evidence of previous gnawing.
- flat splinters with crenelated edges. Their width and thickness can reach several centimetres whereas their width is never greater than 0.5 cm. The facets forming the edge of the pieces are slightly inclined with respect to the flat plane. The ridges are also arranged radially.

The teeth have also been gnawed. The surface of the dentine has usually been nibbled at but a few tooth has been reduced to its crown (Fig. 10c). In rare cases even the enamel has been attacked. These traces are often found in the area surrounding the fracture point suggesting that already broken teeth were gnawed. Half of the teeth were gnawed, as well as 21 % of the teeth fragments without any obvious differences between the different categories of large mammals (Ungulates, Carnivores and Primates). The proportion of rodent teeth that had been chewed was, however, very low at only 2.2 %.

Very few alterations were noted after the gnawing on the bones or teeth. Thus gnawing marks were not interrupted by fractures.

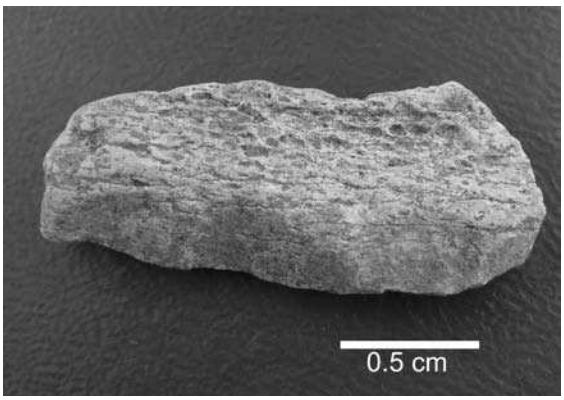

Figure 11: A smoothed bone showing old gnawing marks.

The modifications identified concern the surface patina of the remains. Most of the bones are light coloured and smooth. A small fraction, less than 5% of the bone remains, however, are distinguished by their brown colour and a polish which has also blunt the gnawing marks (Fig. 11). Some of the teeth, especially suids molars and several fragments of walls from muntjac teeth, also have the same brown colour and a smoothing out of the relief caused by gnawing.

Altogether, these observation show that the porcupine is the principal, if not only, agent to have modified the bones. This alteration led to a considerable reduction in size of the bone fragments, which are mostly less then 3 cm. This exploitation was not only of bone because teeth roots have also

been gnawed. The lack of evidence suggesting that any other actors (human or carnivore) have been involved in the accumulation or transformation of the remains is remarkable. The presence of smoothed or even polished pieces is not sufficient evidence to conclude that another taphonomic actor played a role, because these modifications could have been made during the occupation by the rodents.

Discussion

The sedimentological study concluded that an animal lair, most probably of a porcupine, was present. Our taphonomic approach corroborates this interpretation because the principal actor who modified the bones was indeed a porcupine.

The recognition that the site contains the deposits of a lair indicates that the bones in the cave have a purely biological relationship. Furthermore, this interpretation takes into account the fact that the bones were transported into the deep karst context. The porcupine is an animal renowned for accumulating faunal remains in its dens (Brain 1981). Its contribution to the formation of paleontological sites has been especially studied in South Africa and the Middle East (Alexander 1956; Brain 1981; Maguire 1976; Maguire *et al.* 1980; Monchot 2005; Rabinovitch, Horowitz 1994). Alexander (1956) observed evidence that objects weighing as much as 2 kg had been moved. Thus, all of the bone remains recovered at the site in the lower chamber of the Cave of the Monk should have been accumulated by this animal.

Studies describing present-day alterations to bone fossils are carried out in South Africa and the Middle East however. These studies are far to report features similar to those found in Southeast Asia. Particularly, none of these studies reports an almost complete disappearance of the post-cranial skeleton. Nevertheless, the example of the Cave of the Monk is not unique. A number of authors have reported the occurrence of gnawing on bone fossils from caves in the tropical Far East (*eg.* Bacon *et al.* 2006 ; Bien, Chia 1938; von Koenigswald 1938-39; Long *et al.* 1996 ; Pei 1935, 1938; Tougard, Ducrocq 1999; de Vos 1984; Young, Liu 1950). In all these cases, the authors noted the destruction of the teeth roots. Some of these authors argue that the destruction of bones in these sites could be explained by a differential dissolution (*eg.* Tougard 1998). We can accept this hypothesis because some bones are preserved, even if reduced, and their surfaces don't shows dissolution marks. This is confirmed by microscopic observations of sediment slides where an alteration of bones and teeth is noted but is not different between this two categories. The preservation of bones fragments is documented in others Southeast Asian caves as well and it is also noteworthy that the same prism shapes or crenelated splinters that we have described were previously observed by Pei (1938) and Young and Liu (1950) in paleontological material collected in caves in South China. The complete transformation of bones by porcupine gnawing is thus not unique to the Cave of the Monk but a widespread phenomenon throughout all of Indochina. No ethological study of Asian porcupine could explain this phenomenon. Our hypothesis explains this characteristic by the lack of available bone in the tropical forest environment compared to the semi-arid environments, where the available actualist studies were carried out. This shortage could explain the increased consumption of bones collected by Porcupines in Southeast Asia.

The sedimentological study shows evidence that numerous beds were dug between which there were periods during which the den was occupied as shown by the development of a trampled surface. This type of making implies a long formation time. It is possible to understand this time length by relating the number of remains which may be found at the site with the rate of introduction of remains established by studies on modern porcupine dens. In the Cave of the Monk, about 3,500 dental fragments were found in 5 m^2. The surface of the lower chamber that has a surface patterned by beds, and thus functioned as a den, is slightly larger than 50 m^2. Thus we can reasonably assume that we excavated slightly less than one tenth of the deposit and that a complete collection of all material would be about 35,000 dental remains. The Nossob den, studied by Brain (1981), gives an example of the time necessary to accumulate remains in the cave. Teeth are introduced into the den in the form of pieces of cranial mandible. The figure given by the author for the accumulation of these pieces is 80 per century (*cf.* Brain, *op. cit.*). A minimalist hypothesis of 8 teeth per cranial fragment leads to a figure of 640 teeth being introduced per century. Thus the time necessary to introduce 35,000 dental remains in a den is more than 5,000 years. Considering that the cave was probably not occupied continuously, we can estimate that the time necessary to form the site is in the order of one or several tens of thousands of years. This hypothesis should be confirmed by dating the remains held at the bottom and top of the fossil deposit.

Such a duration for site formation has two consequences on the significance of the assemblage collected. First of all, this time frame is longer than periods of climatic fluctuation which could have led to changes in the environment. Recent paleoclimatic investigations actually show that the Monsoon system that controls DSouthest Asian climate and related environments experienced millenial-scale variations during the last glacial cycle (Wang *et al.* 2001; Stott *et al.* 2001). Consequently a faunal assemblage formed during about 10 kyr will lump together species living in distinct environnements. Furthermore, the time frame is large enough so that taxa which lived at different times and consequently different biozones, could be found associated in the same assemblage. This problem of non homogeneity in paleontological assemblages echoes the remarks of Patte (1928) and De Vos (1984), for whom unexpected associations in Pleistocene paleontological assemblages recovered from Southeast Asian caves reflected mixes within the series. The identification of the porcupine as the principal agent in forming Pleistocene paleontological sites supports J. De Vos's hypothesis and indicates that the assemblages can not be considered, from the biochronological and especially the paleoenvironmental point of view, as homogeneous series.

Conclusion

Both geological and taphonomic studies carried out on the infilling and fossil material respectively, show that the Pleistocene faunal site at the Cave of the Monk was accumulated by a porcupine. The criteria for this diagnosis are both sedimentological: facies of debris from a burrowing animal, digging morphology, as well as taphonomic: modifications to bones by this rodent. The series of faunal remains shows a large degree of transformation of the bones which were reduced to small faceted splinters and the consumption of teeth roots. These characteristics are common at paleontological cave sites in the Indochina region and distinguish them from accumulations by rodents described in South Africa or the Middle East. We think that this is linked to the environment in the tropical forests of Southeast Asia.

This finding has double implications on the paleoenvironmental interpretations which can be deduced from this type of series. On one hand the assemblage is a good environmental indicator, in the sense that the accumulations generated by the Porcupine are thought to have sampled the existing taxa from the environment without bias. On the other hand, the series was composed over a long period of time, in the order of one or several tens of thousands of years. This time frame is greater than that of climatic events which faunal associations may reflect. Consequently, the assemblage can not be considered as a homogeneous reference for reconstructing environments. Methods for extracting the information available from these types of assemblages are yet to be devised.

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